Freestanding HEMT Inspired GaN based Optical Pressure Sensor With Grating Coupler

Nagarajan Nallusamy
Optical Communication Lab
EEE, BITS Pilani, Pilani
Rajasthan, India
nagarajsamy90@gmail.com

Sunil Kumar Sharma
Solid State Physical Labaratory
DRDO, Timapur,
Lucknow Road, Delhi, India
sundrdo@gmail.com

Rahul Singhal
Optical Communication Lab
EEE, BITS Pilani, Pilani
Rajasthan, India
rahulsinghal@pilani.bits-pilani.ac.in

Dipendra Singh Rawal
Solid State Physical Labaratory
DRDO, Timapur,
Lucknow Road, Delhi, India
dsrawal15@gmail.com

***Abstract*— One key challenge encountered by photonic integrated circuit is to couple light to and from optical fibers efficiently. The standard fiber used for telecommunication or data communication is single-mode fiber (SMF), which has a mode field diameter (MFD) of less than equal to 10µm at 1550 nm. Efficient coupling from SMF to waveguide with size of hundreds of nanometers is a challenge due to the large mode field mismatch. This problem is usually addressed using two solutions, in-plane or butt edge coupling and out plane (vertical) grating coupling. To ensure good coupling efficiency along with practical feasibility, the grating on freestanding HEMT inspired GaN optical waveguide is a suitable choice for desired wavelength profile with high sensitivity. In this paper, the vertical gratings are introduced on freestanding HEMT inspired GaN optical waveguide for high pressure sensor applications.**

Keywords—optical waveguide, pressure sensor, HEMT, Gallium Nitride

I. INTRODUCTION

After successfully integrating thermal stress and high pressure in GaN-based HEMT optical waveguides [1], study of the AlN-Grating incorporated AlGaN/GaN/AlN optical waveguide for high-pressure sensing applications using SiC substrate is intended. In this paper, with the help of previous results [2], the freestanding AlN-grating incorporated HEMT inspired AlGaN/GaN/AlN optical waveguide is designed for various GaN core and AlN thicknesses. For creating HEMT inspired AlGaN/GaN/AlN optical waveguide, the COMSOL Multiphysics Wave Optics and Structural Mechanics module are used [3]. After successfully optimizing the grating width, pitch and structure, SiC substrate thickness of 35μm and AlN thickness of 90nm is fixed that acts as a nucleation layer. The GaN thickness is initially set at 5μm with $Al_{0.25}Ga_{0.75}N$ thickness of 30nm. The 35μm thick SiC is etched from backside using inductively coupled plasma reactive ion etching (ICP-RIE) method [4]. After the etching process, the HEMT inspired waveguide becomes freestanding waveguide. Further to incorporate the grating structure on the bottom layer of AlN 1μm width is etched with the same ICP-RIE method with the pitch of 1μm at the input and output side. The bottom of the grating inscription left side (Fig. 1) is dedicated to the input light while the right side for output light. The high pressure is applied from the base of the freestanding HEMT inspired waveguide. The cross-sectional diagram of AlN-grating incorporated freestanding HEMT illuminated AlGaN/GaN/AlN optical waveguide pressure sensor proposed here is shown in Fig. 1. In this work, the temperature initially fixed at 30°C and GaN material will withstand pressure up to 150MPa via AlN grating. In sync with previous work reported in references [1] and [2], the pressure range is considered between 90MPa to 150MPa with the transmission range of 1000-2000nm to explore better sensitivity when sensor is exposed to extreme pressure.

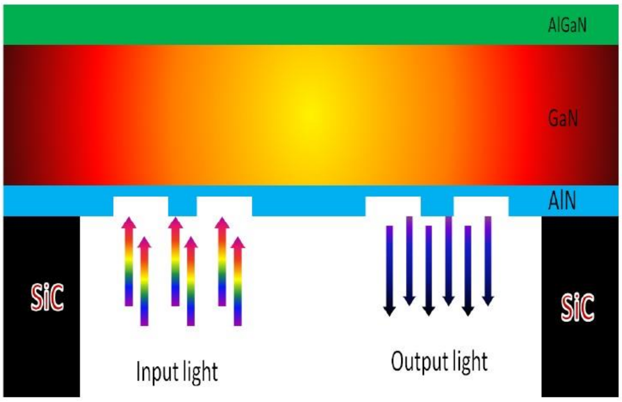

Figure 1. Schematic diagram of the AlN-grating incorporated free standing HEMT structure optical waveguide.

II. GAN CORE THICKNESS OPTIMIZATION

After the optimization of grating width and pitch of AlN cladding [5-6] for the proposed free-standing HEMT inspired AlGaN/GaN/AlN optical waveguide, the pressure range is varied between 100MPa to 120MPa, and further extended up to 150MPa. Initially, the GaN core thickness is fixed at 5μm with AlGaN layer thickness of 30nm, and the nucleation layer is 80nm. Now the pressure is applied at the bottom of the device; precisely to the AlN layer. The light is launched into the input port, and the output light is observed in the right-side port (Fig. 1). Using the FEM analysis, the transmission spectrum is evaluated for the wavelength range of 0.5μm to 3 μm. The corresponding transmission plot is depicted in the Fig. 2(a). From the observation, precisely at 1700nm, the transmission of light varies linearly with small change. For the rest of the few wavelengths, transmission of light changes but randomly. Due to the lower transmission sensitivity at 1700nm, the GaN core thickness optimization is necessary further to achieve high sensitivity.

For optimizing the GaN core thickness, the GaN core thickness is reduced from 5μm to 4.1μm with an decrement of

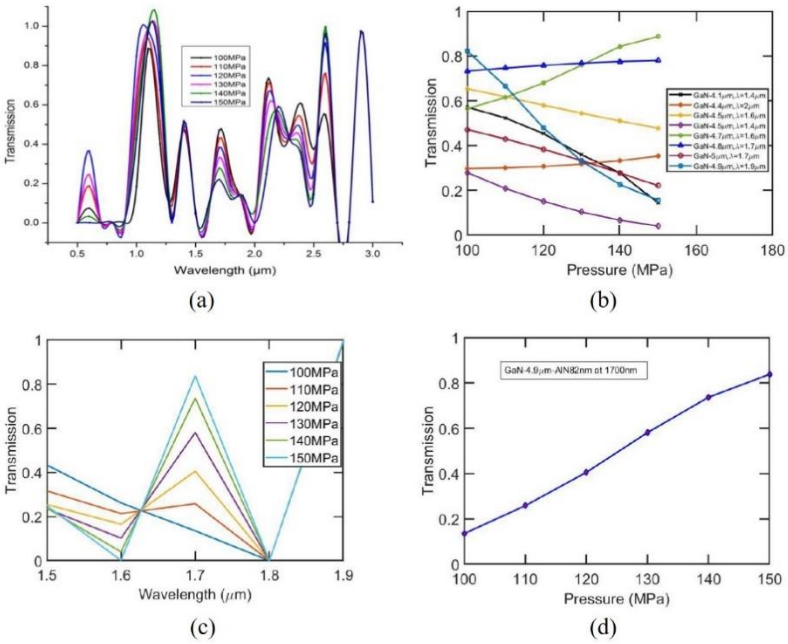

Figure 2. (a) The transmission spectrum of AlN grating incorporated freestanding inspired HEMT structure waveguide under different pressure at the GaN core thickness of 5$\boldsymbol{\mu}$m; (b) Sensitivity plot for different GaN core thickness under different pressures; (c) The transmission spectrum of GaN core thickness of 4.9$\boldsymbol{\mu}$m with grating thickness of 82nm; (d) The sensitivity plot for GaN core thickness of 4.9$\boldsymbol{\mu}$m with grating thickness of 82nm under the pressure range of 100MPa to 150MPa.

0.1μm. While tuning the GaN core, the light transmitted with different wavelengths and is portrayed in the Fig. 2(b) for different core thicknesses. Interestingly, 4.4, 4.7 and 4.8μm core thicknesses show the linear changes from low transmission power to high power transmission at the wavelength of 2000,1600 and 1700nm, respectively. The rest of core thickness 4.1, 4.5 and 4.9μm shows the transmission variation from high to low. Among all, 4.5μm core thickness gives linear changes in two wavelengths, namely 1400nm and 1600nm, with less sensitivity. Compared to all GaN core thicknesses, 4.9μm core thickness shows high sensitivity to the pressure range of 100 to 150MPa. The linear relation between varying pressure and transmission intensity suggests that pressure sensing can be done using a simple photodetector based power meter.

Further the AlN grating thickness is scanned and optimized for better performance. For this optimization, minor steps of 1 nm are used because the grating width and pitch as well as GaN core thickness are already optimized. For this, the grating thickness of 78, 79, 81, and 82nm are chosen. Again, with small variation, nonlinearity in transmission is observed except at 82nm thickness. Interestingly, at 82nm thickness, linear but sensitivity in a reverse manner is observed i.e. with increase in pressure, transmission increases but the phenomenon is observed at a wavelength of 1700nm. The corresponding transmission and sensitivity plot is shown in the Fig. 2(c) and 2(d). These analyses of incorporating the AlN grating over freestanding HEMT inspired GaN optical waveguides show high sensitivity at a wavelength regime with high sensitivity. Further by tuning parameters/dimensions of the whole device structure, the pressure range can be varied.

III. Conclusion

In this paper, an AlN grating embedded freestanding HEMT inspired AlGaN/GaN/AlN/SiC optical waveguide based high-pressure sensor for harsh environment studies is proposed. To obtain the high sensitivity and desirable wavelength regime width and pitch of the gratings as well as GaN core and AlN thickness is essentially tuned. The proposed sensor yields high sensitivity at the desired wavelength of 1900nm and 1700nm by carefully adjusting all the design parameters. The proposed pressure sensor design can be utilized to develop economical sensor with high-temperature stability. The grating embedded HEMT based optical sensor plays a major role in the near future for extreme surroundings discovered at defense and industrial environments.

Acknowledgment

This work was financially supported from Solid State Physics Laboratory, Defence Research and Development Organization, MoD, Gov. of India (Ref. no. 115/CARS-79/TS/SPL/19, dated 11.12.2019).

References

[1] N. Nallusamy, R. Singhal, S. K. Sharma and D. S. Rawal, "HEMT Inspired GaN Optical Waveguides: Analysis Under Thermal Stress and Prospects," in IEEE Transactions on Device and Materials Reliability, vol. 22, no. 3, pp. 424-430, Sept. 2022.

[2] N. Nallusamy, R. Singhal, S. K. Sharma and D. S. Rawal, High-Electron-Mobility Transistor-Inspired Freestanding AlGaN/GaN/AlN Optical Waveguide for High-Pressure Sensing Applications. Phys. Status Solidi A, Volume220, Issue7, 2200637, April 2023.

[3] https://doc.comsol.com/5.3/doc/com.comsol.help.sme/StructuralMechanicsModuleUsersGuide.pdf

[4] H. K. Sung, T. Qiang, Z. Yao, Y. Li, Q. Wu, H.K. Lee, B.D. Park, W. S. Lim, K.H. Park & C. Wang, Vertical and bevel-structured SiC etching techniques incorporating different gas mixture plasmas for various microelectronic applications, Scientific Reports 7, 3915, 2017.

[5] X. Zhou and H. K. Tsang, "Photolithography Fabricated Broadband Waveguide Grating Couplers With 1 dB Bandwidth Over 100 nm," in IEEE Photonics Journal, vol. 16, no. 1, pp. 1-6, Feb. 2024.

[6] S. KP, S. Raghavan, and S. K. Selvaraja, "High-Efficiency Grating Fiber-Chip Couplers at Telecom Wavelength in Gallium Nitride-on-Sapphire Waveguide Platform," in Conference on Lasers and Electro-Optics/Europe (CLEO/Europe 2023) and European Quantum Electronics Conference (EQEC 2023), Munich, Germany, Technical Digest Series, Optica Publishing Group, 2023.